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*On the Four Visible Ingredients in Banded Bituminous Coal :
Studies in the Composition of Coal, No. 1.*

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[PLATES 11 AND 12.]

Even after a century of investigation coal remains a complex mass of which the component parts can neither be handled nor separately identified. Many authors have recognised a variety of plant remains in coal, and the specific identification of these organisms and tissues has made good progress; but such work is truly palæontological, and the points of interest in it are the organisms and not the coal mass of which they form a part.

From another point of view coal is a rock, but, unlike most rocks, the nature and orientation of its component parts are scarcely known. One of the most distinguished of living geologists once said to me that he would like to have available about microscopic sections of coal rationalised data comparable with those already obtained by petrologists about thin rock sections. The present paper is a contribution in that direction. It is an attempt to present systematically certain observations made incidentally in

the course of the joint researches Dr. R. V. Wheeler and I have been following out on various other aspects of the hydra-headed "coal-problem."

In this paper the only type of coal dealt with is British palæozoic (Coal Measure) streaky bituminous coal, the kind of coal which every household and most factories employ. The appearances of the microscopic sections of Cannels, Bogheads, Anthracites, and "Lignites" are each distinctive and significant, but they are not dealt with at all in the present paper.

The actual coal chiefly used in the research was the various bands of the Hamstead Colliery (Birmingham), and to Mr. L. Holland, the manager, and the Company, I am much indebted for facilities to collect the coal myself *in situ*, and for various courtesies; also to Mr. P. S. Lea I am indebted for carefully selected samples from the "Eight-feet seam" from West Cannock Colliery, S. Staffordshire. The observations were checked and supplemented by the examination of various other bituminous coals from widely separated localities.

In their text-book on the Petrology of Sedimentary Rocks, Hatch and Rastall (1913) describe ordinary coal as follows: "The humic or bituminous group includes the ordinary house, cooking, and steam coals, of which the appearance is so familiar as scarcely to need description. As a rule, they consist of a series of alternating bright and dull layers; in the latter only can remains of vegetable tissues sometimes be seen."

This may be taken as summarising a prevalent view; but, as will be seen on reference to p. 484 below, a conflict of opinion exists about the presence of plant tissues in the "dull" or the "bright" layers; some of the leading authors taking a view opposite to that of Hatch and Rastall, and stating that it is only in the "bright" layers that tissues are to be seen.

Preliminary Statement of the Present Contribution.

Essentially the present contribution to the subject consists in the explicit recognition not of mere "dull" and "bright" bands, but of *four* distinctive and visibly differing portions forming the mass of an ordinary bituminous coal; and the demonstration of the fact that these four portions can be recognised and separated from each other both macroscopically, by hand, and microscopically in thin sections; and that, further, these four portions react so differently to certain simple chemical treatments as to indicate that their chemical molecules should be substantially different from each other. Diagrams of these points, and of the relations of the four constituents to each other in an ordinary sample, as well as colour illustrations of the same in thin sections, are given.

These four distinguishable ingredients, all of which, in varying quantities, are to be found in most ordinary bituminous coals, I name provisionally as follows :—

- (i) Fusain* The equivalent of “mother of coal,” “mineral charcoal,” etc., of various authors.
- (ii) Durain† The equivalent of “dull” hard coal of various authors, the “Mattkohle” of Germans, etc.
- (iii) Clarain† } Together the equivalent of “bright” or glance coal of various authors, the “Glanzkohle” of Germans. Sometimes the “bright” coal of an author seems to be the vitrain only.
- (iv) Vitrain† } (Conchoidal fracture, brilliant in appearance.)

[These names, I am fully aware, do not represent chemical entities (with the possible exception of vitrain), but they do represent tangible entities of the same useful order as “jet,” “granite,” or “cheese.”]

The generally “streaky” or banded nature of a seam of coal is of varying orders of magnitude, and as one magnifies a banded piece of coal more and more it becomes increasingly apparent how finely laminated it may be. Hence, a diagram of the arrangement of the bands natural size, magnified by 4, and another by 10 or even 20 diameters, may all show essentially similar lenticular intercalated lamellar structure.

In hand specimens sometimes bands two to four inches or more in thickness may be all “dull” coal, little, if at all, streaked with “bright;” and perhaps above or below that may be three or four inches of glossy “bright,” only finely streaked with dull. Most coals, however, are more mixed than that, and the average “dull” band is from a quarter of an inch or more in thickness, and is all through visibly streaked with fine lenticels of “bright,” while the “bright” portions are streaked with very variable bands of “dull.” Both the “dull” and the “bright,” both the fusain and the vitrain, are all essentially lenticular masses; these are often so horizontally extended and so thin that they create the impression of being fine horizontal bands. With very few exceptions they lie approximately parallel to the bedding plane of the deposit. The fusain is the least regular in its arrangement, but on the

* The French name, adopted into English by J. J. Stevenson (1911–13) and Stopes and Wheeler (1918), to replace our native unwieldy and misleading names “mother of coal” and “mineral charcoal.”

† The first use of new terms suggested by the present author, and each based on a Latin root descriptive of the substance and terminated in *-ain* to match *fusain*. The latter word is a French word used by geologists in a specialised sense. It is based on the Latin *fusus*, and its application to the “mineral charcoal” came about in a circuitous way. The roots I have chosen are obviously and directly descriptive.

whole its more wedge-shaped portions tend to lie so as to be most apparent on the surfaces which are split parallel to the bedding. The appearance of fusain has very often been described.

The fourth ingredient, the vitrain or brilliant bands, have been less considered in the past, but are, as a matter of fact, particularly interesting. These brilliant bands, in a favourable sample, are very definitely delimited from the rest of the coal, much more so than are either the ordinary bright clarain or the dull durain from each other, which, owing to the finely lamellar nature of the coal in which they are interlarded, are sometimes hard to separate. The true vitrain, however, generally forms a very definite and often sharply straight-cut band, varying from 2 to 6 or 8 mm. thick. There are, of course, brilliant streaks of smaller size, down to almost hair-like flecks. The larger, however, are the more typical vitrain zones. They are notably less numerous and less in quantity in most coals than are the ordinary glossy bright clarain, and in some coals are scarcely to be found. They should be carefully distinguished from the very glossy almost vitreous thick zones of bright coal sometimes forming a great quantity of a seam, which, however bright, will always show streakiness however subdued. A true piece of pure vitrain is not streaky even with a magnifying glass.

In studying minutely the four different portions of a coal, one point should be borne in mind concerning the samples used; and that is, that they should all four be selected *in situ*, and as near to each other as possible. In the mine, therefore, blocks should be cut out, each showing all four ingredients as well differentiated and as nearly contiguous as possible. In this investigation I worked with well banded blocks about 6 by 8 inches cube. In the course of the work a large portion of each sample block is broken up, and the zones where the intercalation of the "dull" and bright is very fine, are useless for the isolation of the pure ingredients, as they cannot then be separated by hand. It must be recognised further that both durain and clarain can really never be got absolutely free from some streaks of each other, but if in the durain there are only few and hair-like streaks of clarain, and in the clarain only few and hair-like streaks of durain, they can serve for all practical purposes as pure enough to indicate the relative characteristics of really pure clarain and durain. With care, both fusain and vitrain can be separated by hand from favourable samples in a really pure state.

The Appearances of the Four Ingredients with the Naked Eye, i.e., their Macroscopic Appearances.

Fusain occurs chiefly as patches and wedges, somewhat flattened parallel to the bedding plane, and often with rather square-cut ends. It consists of

powdery, readily detachable, somewhat fibrous strands. The orientation of the fibrous structure tends to be lengthways in relation to each wedge, and the various wedges on a bedding plane lie at various angles to each other, so that in any given light some appear dull and some glisten according to the direction the light catches the fibres.

The fusain is readily separated from the rest of the coal (which is all firmer than it in texture) by delicate scraping with a blunt knife, when the short, fibrous strands and small, sharp-pointed, irregular fragments fall freely on to a paper laid so as to catch them.

Where, as may happen, a thick wedge of fusain is contiguous with a true vitrain band, the fusain may appear as though embedded or sunk in the vitrain (*cf.* the text-fig., 2*f*). The fusain can then be entirely scooped out, leaving exposed on the vitrain the hollow in which it lay, the surface of this vitrain hollow being curved and smooth. The contact surfaces of both clarain and durain with fusain, however, are much less precise, and an impression of the fibres of the fusain is generally left on the harder durain or clarain after all the friable detachable fibres of the fusain have been removed.

Durain occurs generally as bands of very variable thickness, and when seen in a face at right angles to the bedding plane, they appear parallel to it, though, if traced far enough, they generally reveal their ultimately lenticular shape. Wider bands of comparatively pure durain are less common, but bands, 2, 3, or more inches thick are often sharply differentiated from the adjacent streaky bright clarain.

Durain is hard, with a close, firm texture, which appears rather granular even to the naked eye. However straight the break across it, the broken face is never truly smooth, but, if looked at closely, always has a finely lumpy or matte surface (see Plate 11, fig. 1). Generally, even in the dullest of durain bands a few (or many) flecks or hair-like streaks of bright coal are to be seen.

The intercalation of narrow bands of durain and clarain tends to increase at the junction of the broad "dull" and the broad "bright" bands, so that there is no large surface of contact between them which is sharp cut and well defined, even the purest clarain and the purest durain tend to have ravelled edges, which interlock (see text-fig. 4, junction between *c* and *d*).

Clarain occurs generally as bands of very variable thickness, and when seen in a face at right angles to the bedding plane they appear parallel to it. Like durain bands, they are ultimately widely extended lenticular masses. Clarain, even when considerably streaked with durain, has a definite and smooth surface when broken at right angles to the bedding plane, and these faces have a pronounced gloss or shine. This surface lustre is seen to be

inherently banded, as well as to have bands of fine durain intercalated between its own bands (see Plate 11, fig. 2).

Vitrain occurs as definite rather narrow bands, in some instances straighter and flatter than the other bands of coal, and in some instances more obviously lenticular. True brilliant vitrain bands are often markedly uniform in thickness for considerable distances, and are commonly from about 2 mm. to 3 or 4 up to 6 or 8 mm. thick, but are very seldom much more than 8 to 10 mm. thick. The limiting layer between the vitrain and the contiguous clarain or durain is generally sharply marked and is often clean-cut definite surface (see Plate 11, fig. 3). A single brilliant band does not exhibit the fine banding detectable even in the brightest of clarain, but is a coherent and uniform whole, brilliantly glossy, indeed vitreous, in its texture. The compact vitreous band may split up readily in the fingers to small cube-like segments, but more generally they break irregularly when forced, as with a penknife point, when the curved irregular faces have well-marked conchoidal fracture (see Plate 11, fig. 4). As was mentioned in connection with fusain, the contact-surfaces of vitrain with the other ingredients of coal tend generally to be well defined with a firm, hard, and glassy face.

Effects of the four Ingredients on the Photographic Plate.

The four ingredients are differentiated by their potency in making images of themselves directly (contact photos.) on sensitive plates.

Small pieces of approximately pure durain, clarain, and vitrain were placed on a negative, together with a little of the powdered fusain. All were taken from one sample.

By the method first described by Russell (*cf.* Russell, 1906, 1908, and used by Platt and Wheeler, 1913), a contact photo. was obtained.

The banded appearance of the contact photos. from blocks of ordinary streaky coal has been observed by the previous workers; the interest and novelty of the present photo. (for which I am indebted to Dr. Wheeler) lies in the very noticeable difference in intensity of the images made by the vitrain and the other parts of the coal. This can be seen on Plate 11, fig. 5, at A. That the brilliant vitrain should be the portion of the coal to make the most intense image on the plate is a point the significance of which is better discussed after some of the other characteristics of the four constituents have been considered.

Behaviour of the four Ingredients with certain Chemicals.

Work with a variety of chemicals is being undertaken, but the present paper is intended mainly to lead up to the microscopic distinctions between

the four constituents, so that only two relevant chemical treatments will be noted here.

(i.) *With 10 per cent. KOH in Water + twice the Volume of 50 per cent. Alcohol* the behaviour of vitrain is interesting. Small pieces (about 3×5 or 4×6 mm.) of pure vitrain placed in this solution, without any previous treatment, and left in the cold, become slightly swollen and softened without the addition of any acid or any other chemical substance. In three or four days pieces in this solution acquire the consistency of hard cheese or soap, and with an ordinary razor thin flakes can be cut from them.* The vitrain alone, however, is affected in this way. The clarain largely breaks down when touched after being in the solution, and is hard and irregular to the razor's edge. The durain becomes so friable that any attempt to cut it with the razor breaks it down to a hard, gritty powder.

The penetrating power of alcohol should not be forgotten in considering the behaviour of coal to weak caustic solutions in it: a solution in water alone has not the same effect.

(ii.) *With strong Nitric Acid + a few Drops of Hydrofluoric Acid, followed later on by Neutralisation.*

Otherwise untreated samples of coal, of the three specified ingredients of coal other than fusain, placed in the mixture of acids, all tend after some days to break down to some extent, and the acid becomes tinged with brown. If left in the cold the pieces do not entirely disintegrate, but remain as smaller pieces. If after a week or so the acid is poured off, the pieces drained and then neutralised with strong potassium hydrate, they may still retain their solid nature. If the black solid mass is now placed at the bottom of a relatively large vessel, and water added in quantity, a proportion of each goes into solution as follows:—

Vitrain goes completely into solution if care is taken to select quite pure samples of vitrain. With the rapid addition of water there is at once formed a quantity of frothy "head," which ultimately, but very slowly, settles down. The "solution" looks quite black in bulk, but when it fills a thin tube and is held against the light, it is seen to be a clear tea-coloured liquid, containing no floating particles or suspended jelly-like precipitate. Exact measurements of quantities are not yet significant, but I found that 2 grm. of pure selected vitrain yield, with the addition of the necessary water, half a litre or

* As a similar behaviour has been described for the run-of-mine *Lignites*, it should be remembered that the coals dealt with in the present paper are typical hard, true black, bituminous, palaeozoic coals; and that one of the standard criteria of distinction between lignite and true black coals is the fact that aqueous solutions of potassium hydrate dissolve the former to some extent, with a brown solution, but do not affect the latter.

more of a solution so strong that it looks coal-black in bulk. Where the vitrain is quite pure there is no undissolved *débris* at all; but if fine streaks are visible in part of the original material, a few small spores and fine *débris* may be found at the bottom of the flask.

Clarain also goes largely into solution; the "head" of froth, however, is less in quantity and subsides more quickly. After standing, some *débris* settles at the bottom of the vessel, and this *débris* has, under the microscope, certain definite characteristics (see p. 478). The solution appears quite black in bulk and clear tea-coloured in a fine tube.

Durain forms no real froth, and the "solution" is rather paler than that of clarain, at first looking equally dark, owing to the number of very minute opaque particles suspended in it. After standing, the *débris* settles down and is seen to be considerable in quantity. Its microscopic appearance is described below (p. 478).

Fusain forms no froth and no true solution, the water generally remaining colourless, or being no more than straw coloured. The particles of *débris* are very heavy and numerous, settling more quickly than from the other coal ingredients (*cf.* p. 478).

In order to present these differences graphically, equal weights of each of the four coal constituents were taken, treated ultimately with equal amounts of water, allowed to stand overnight so that the *débris* settled, the clear solution then decanted off, leaving in each vessel 20 c.c., with the *débris*. Each vessel was then well shaken up, so that whatever was in each was mixed and held in suspension, and then from each a narrow tube was filled. These four tubes were standing vertically, when settled the contents presented the appearance shown in fig. 5, Plate 12 (coloured illustration).

The proportion of *débris* thus separated was much greater in the fusain tube than in the others; and in the tube the particles settled relatively quickly, and were big, black and opaque. The durain tube showed less *débris*, filling about one-third of the tube when the particles had settled, and the particles themselves were smaller, and not all opaque, but some were brown and translucent, while the solution was tea coloured, and in it were for long suspended fine amber coloured fragments of plant tissue.

The clarain tube showed still less *débris*, about one-sixth or less of the tube settled quickly, but for some time the finer generally amber coloured and clear particles of plant tissue, spores, etc., remained suspended in the clear solution, which was the colour of strong tea.

The true pure vitrain had no *débris*, save for an intrusive speck or two. The clear solution was strong tea coloured.

Micro-photos of the *débris* of the above experiments show some of their

characteristic features. The three photos were all taken with identical illumination, magnification, and time exposure. The fusain *débris* (Plate 11, fig. 6), is almost entirely composed of angular, fibrous, sharp-pointed fragments of very varying size, black and opaque.

The durain *débris* (Plate 11, fig. 7) is largely composed of irregular but more polyhedrally shaped fragments, black and opaque, some of which have transparent edges; mixed with the opaque particles are clear, irregular fragments, which appear to be portions of the broken up walls of the macrospores. Scraps of cuticles, and so on, are sometimes seen, but are seldom recognisable. The opaque fragments generally preponderate in at least about the proportion of three to one.

The clarain *débris* (Plate 11, fig. 8) is much finer as a rule, and consists preponderatingly of clear, brown and amber coloured fragments of irregular size and shape. Mixed with these are some opaque black granules and fragments, possibly due to small inseparable streaks of durain. In the clear clarain *débris* can be recognised many cuticle fragments, pieces of or complete spores, and also oval or rounded particles which I have come to the provisional conclusion represent the *cell-contents* in a special condition, from which the surrounding cell walls have been dissolved away.

Clarain *débris* repays study with the high magnification, but for comparison with the other two *débris* it is shown in the figure on the same scale.

The Appearance of the Four Ingredients in Microscopic Sections of Untreated Coal.

A number of carefully selected blocks and small pieces were cut without any treatment save that necessary for sectioning by the grinding method. The coal is consequently quite unaltered (save for the permeating canada balsam mixtures which attach the sections to the glass) both in appearance and essential structure. The microscopic appearance of the four constituents are most noticeably different and characteristic, as will be apparent on reference to Plate 12, figs. 1-4 (coloured).

Before describing them in detail, I wish to say a word about coal micro-sections, many of which have been described by various authors. In several publications there are available for reference a number of excellent photographic reproductions of the structure and appearance of various coal sections. The reader should specially refer to Lomax (1911, 1915); White and Thiessen (1913); Jeffrey (1914, 1915); and Hickling (1917); and for critical references to the literature to Stopes and Wheeler (1918). All the illustrations above quoted show the finely stratified lamellar nature of the

material in the coal sections, among which are recognised various plant tissues, resin bodies and other things in the coal.

Many carefully marked banded pieces of coal, and also small pieces composed of each separate ingredient as pure as could be obtained were cut into sections in the course of the present work, and from them the persistence of certain characteristics in each of the four types was made evident. Describing the four ingredients now recognised in the order hitherto followed:—

The *fusain* (which, though friable, at times forms patches or lenticels in the coal, from which more or less complete sections can be cut) is almost black, opaque, and when it shows the cellular structure of the wood from which it was formed, it reveals the walls as much thickened and the cell lumina as being generally empty. When the section is approximately at right angles to the direction of the wood fibre, an appearance as shown in Plate 12, fig. 1 (coloured), results. This illustration, though in natural colours, looks almost black and white, save at *s* where is the gleam of an adjacent spore, showing the colour contrast between fusain and the other portions of the coal in section.

The botanical nature of the various plant fragments sometimes identifiable in the fusain does not concern us here; their general *optical* effect varies but little whatever species they are.

The *durain* being firm and hard in texture is more easily cut and ground than fusain, but as it tends to be rather granular, it is more difficult to finish finely than the more coherent and softer clarain. Sections show a granular matrix of roundish or polyhedral fragments, the majority of which are blackish and opaque. The granules are closely packed and form a coherent mass, but mixed with them are the most characteristic spore exines. These may be whole or in fragments. The macrospores are most conspicuous, and their very thick exines are clear and brilliantly coloured, almost red, though when thinner they are reddish gold to pale gold or amber colour. In durain the ground mass of rather opaque granules, and the large clear macrospore exines tend to preponderate, see Plate 12, fig. 2 (coloured). There may or may not be a number of small microspores mingled with the granules forming the bulk of the durain. Throughout the texture of the less pure, streaked durain are seen in section small, clear, generally lenticular bands or flecks of a more golden colour. These are the streaks of clarain which so commonly lie interbedded with the durain (*cf.* p. 474). The purer the durain the fewer of these clear patches are to be seen in the section. These should be distinguished from certain other light coloured bodies sometimes to be seen in the durain, viz., the supposed “resin” bodies and other small distinctive *

granules. These, though sometimes locally abundant, are less characteristic of durain than of clarain. One may say that, on the whole, durain is essentially composed of a high proportion of opaque, fine granules, with many macro- and microspore exines scattered through it like currants in a pre-war pudding. Even in a small streak of durain the spore exines tend to be flattened and oriented so as to lie parallel to the general bedding of the coal seam.

The *clarain* is the easiest portion of the coal to cut into good sections, and is the most interesting to the palaeobotanist, for in the clarain lie the greatest variety of recognisable plant tissues and structures. Clarain is essentially clear, as contrasted with the opacity of durain. There may be in it clear bands and zones showing much disintegrated plant substance, also bands of clear cuticle, spore exines, "resin-bodies," and other structures of various shades from pale yellow to a rich reddish-amber, the great majority of which are translucent or semi-translucent (though among them may be some opaque granules and particles), and among this variety of material plant stem tissues, leaf-tissues and so on may be preserved and may even fill the whole area of the sections. Plant tissues so preserved are also essentially translucent, though colour contrasts of the various minute structures present make the cellular tissue evident. There are also, of course (see p. 475), the opaque streaks of durain which are common in clarain, and should be looked on as an impurity in it. As a general rule, one may say of clarain that it is essentially translucent in thin section, and the purer the clarain the more are all its components of some degree of translucency [see Plate 12, fig. 3 (coloured)]. Even in a small area of clarain, that forming a fine bright streak in a dull piece of durain, for instance, the arrangements of the materials in it tends to be parallel to the general bedding of the coal seam. Comparison of a number of sections with the various published illustrations makes it clear that clarain is the happy hunting ground of the palaeontologist in search of preserved remains of the tissues composing coal, and fortunate it is for him that so large a proportion of most ordinary seams are more or less pure clarain. In it remains of all kinds are to be found, ranging from very small fragments up to preserved stem tissues running for inches unbroken in the coal. It appears that the richer detail and variety of structures in the clarain, more or less pure, have attracted most recent workers, and have formed the basis of the great majority of the good illustrations hitherto published on the micro-structures in coal.

Vitrain is, in my experience, unobtainable pure in *large* sections, as true vitrain occurs almost entirely in thin bands, which tend to break into small segments. In section, when pure, its essential characters are its translucency

(in which it resembles clarain) and its structureless and uniform texture, in which it differs from all other parts of coal. As it is technically difficult (my own cutter and Mr. Lomax, to whom I sent samples, find it impossible) to grind down this substance to absolute uniform thickness over the whole area of the section, the section has areas shading from pale gold to ruddy brown, but these obviously depend on the varying thickness of the slice examined: the mass is, uniform in its structureless nature. Plate 12, fig. 4 (coloured), shows the yellowish to dark amber colour of the uniform mass. Scratches show up on the surface very annoyingly, and are due to minute irregularities even in the finest polishing stone; they are unduly conspicuous in photos., but when the eye examines a number of sections it readily detects the essential uniformity of the vitrain, and its structureless nature, as of a hardened glue or jelly. In it may be seen an occasional isolated spore, or a fine streak of durain may have been included, but if the purest, most brilliant vitrain is selected, it is essentially homogeneous. The illustration given on Plate 12, fig. 4 (coloured), illustrates this, though imperfectly, and offers a contrast to the standard sections of durain and clarain (Plate 12, figs. 2 and 3).

There is, consequently, in *pure* vitrain no banding or differentiation of parts in relation to the bedding plane of the deposit, though any individual mass of vitrain generally itself forms a horizontally extended band, lying parallel to the bedding of the coal.

The original thesis of this paper is borne out in the above details of these very various observations, and I think we may now see in ordinary bituminous banded coal four recognisably distinct and differentiable ingredients, for which I propose the names fusain, durain, clarain, and vitrain. These four, though difficult to separate completely, and ever tending to be interbanded and to penetrate each other, can yet, in most ordinary banded seams, be recognised by the naked eye, locally pure, and obtained by hand separation nearly pure. Such separated samples from a few adjacent inches of coal show marked differences: (i) in their effect on sensitive plates, (ii) in their behaviour with various solutions, (iii) in the quantity and character of the *débris* they yield under treatment, (iv) in the microscopic details of this *débris*, (v) in the microscopic appearance of the substances in thin, ground, untreated sections. Further, in their chemical analyses, distillation products, and so on they differ; but these features will be dealt with by Dr. Wheeler.

The above data apply particularly to the well-banded, relatively undisturbed coals of the Midlands, of which the Hamstead Colliery yields excellent examples. In some other seams, particularly those visibly affected

by earth movements, the whole of the coal may have been slightly dislocated and altered in minute steps, which, though not affecting either the bedding of the roof and seam, or the coherence of the seam, may yet have destroyed the interbanding of the four ingredients, as described above. Such coal may all look very "bright," and may have only the streaks of fusain to represent the "dull." An example of such a coal is seen in part of the Pentre seam of South Wales, in which one might search for long before finding a block with anything but "bright" and fusain in it.

Naturally, in order to obtain any light on the characters of these four constituents, my endeavour was to obtain samples which contained the ingredients in layers of sufficient size and purity for the respective substances to be dealt with nearly pure. In most banded bituminous coals such samples can be found if sought for, though they may be insufficient in bulk to handle easily. The coal in bulk is generally composed of masses more intermingled, so that small bands or lenticels of one or the other ingredient are interbedded, and only separable by hand with great labour.

In general, therefore, sections of coal which have formed the subject of the investigations of previous workers will be found to contain at least two, and probably more, of the four constituents so laboriously separated in the present work.

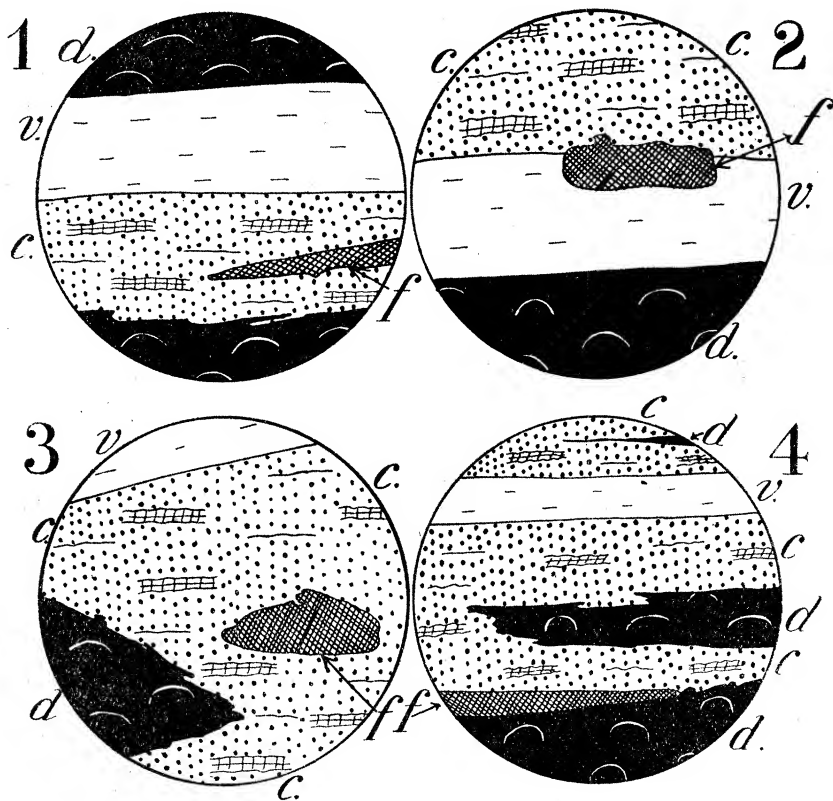
It may be useful, and is certainly in keeping with the attempt to obtain a parallel to petrological knowledge, to give in a clear diagrammatic form the orientation of the ingredients generally to be observed. The accompanying four diagrams in the text (text-figs. 1-4) built up of conventional symbols representing each of the four above-named ingredients, illustrate the kind of distribution of the ingredients likely to occur in sections, taken without any special selection, from an average finely banded piece of bituminous coal.

These diagrams actually represent a low scale of magnification, four diameters, but, owing to the laminated nature of the coal, were more finely laminated regions taken and multiplied five or even ten times this, it would be possible to find areas which could justly be represented by the same diagrams.

An interesting feature to note is the comparatively straight line of contact between vitrain and either clarain or durain adjacent to it, when cut at right angles to the bedding plane; while the contact surfaces between clarain and durain tend to interlock in fine laminae. Fusain tends to form irregular patches and wedges or lenses, which may have very small jutting projections into either the durain or clarain (see text-fig.) and in the vitrain may lie sunk in a comparatively smooth hollow (text-fig. 2).

As these four ingredients of coal which I provisionally delineate are none

of them (with the possible exception of vitrain) actually homogeneous, nor are chemical molecular units, they do not even approximately represent the crystals in a petrological section of a rock; nevertheless, when represented on a low scale of magnification and in diagrammatic fashion, it may not be devoid of suggestiveness to compare such sections with those so useful to petrologists.



TEXT-FIGS. 1-4.—Diagrams of micro-photographs of sections of "streaky" bituminous coal, indicating the characteristic distribution of the four ingredients: *c*, clarain; *d*, durain; *f*, fusain; *v*, vitrain.

I hesitate to elaborate the matter at this early stage, but it seems possible that we have here a first step in the building up of an exact knowledge of the "physiography of coal sections," though the nature of the case debars the development of the theme from following quite the lines of the "microscopical physiography of minerals" laid down by Rosenbusch.

While the present recognition of four distinct ingredients in coal is, so far as I am aware, new, many authors have noted the banded appearance of

coal, and particular attention has been paid to the "dull" and "bright" zones. The early and most excellent paper of Karsten (1826), in which the "matt" and "glanz" coal layers were not only described but correlated with preliminary chemical examinations, has been followed up by Rogers (1843); Dawson (1859, 1866, 1871); Grand'Eury (1882); Renault (1882); Von Gümbel (1834); Wethered (1885); Gresley (1892); Seyler (1907); Barsch (1908); Stevenson (1911); Dowling (1911); Grout (1911); Lomax (1911); Pringle (1911); White and Thiessen (1913); Hatch and Rastall (1913); Grummitt and Hickling (1914); Jeffrey (1914); Lomax (1914, 1915); Strahan and Pollard (1915), as well as by many references of minor importance.

In these statements there is much difference of opinion, some authors stating that plant structure is found only in the "dull," others that it is found only in the "bright" coal. A detailed consideration of the views of Dowling (1911), White and Thiessen (1913), and Hickling (1917) is essential, but must be postponed to a later paper, when I hope to go into the matter more fully.

The lack of all preserved structure in "bright" coal maintained by various authors, and its jelly-like nature, suggested by Dowling, for instance, in my opinion indicate that the term "bright," as previously used, has covered both the bright clarain and the brilliant vitrain, differentiated in the present work, and also the secondary "brightness" resulting from natural agencies acting on a coal like the Pentre. So that in the past some authors have meant by "bright" the structureless brilliant vitrain, while others by the same word have meant the bright clarain which so often is full of plant structure; hence has arisen the directly conflicting statements about the presence of plant structure in "bright" and other coal.

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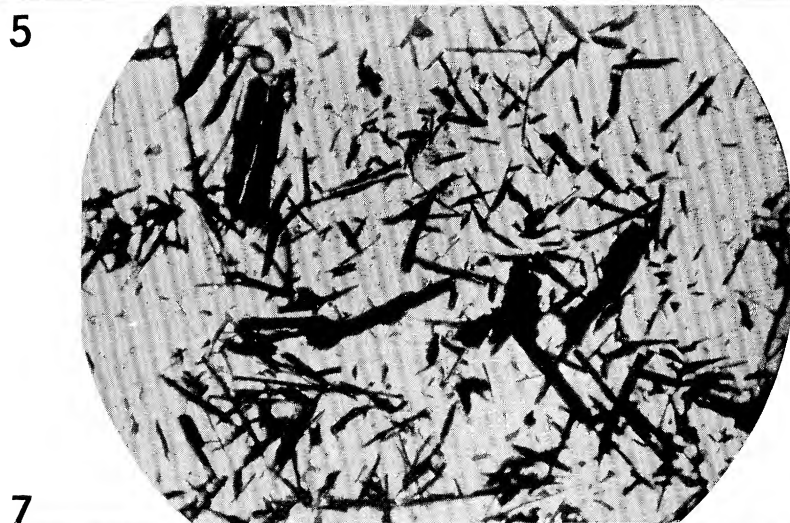
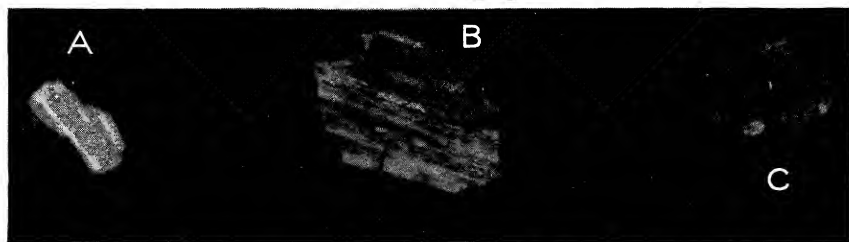
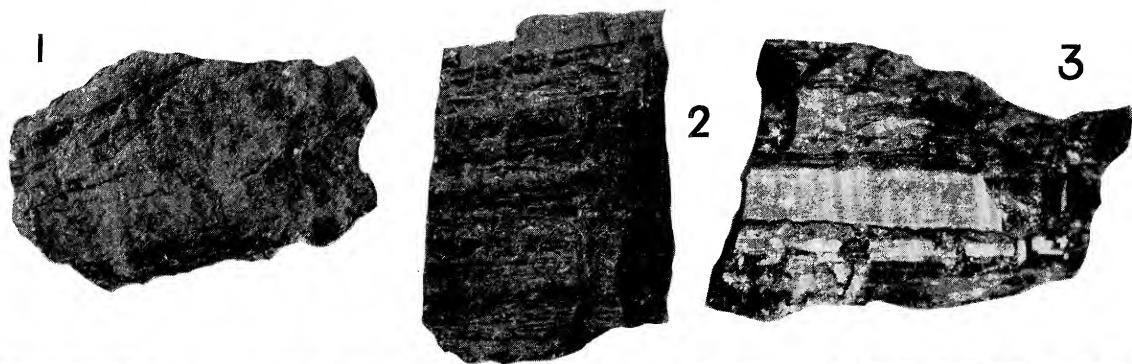
DESCRIPTION OF PLATES.

PLATE 11—The plain Plate.

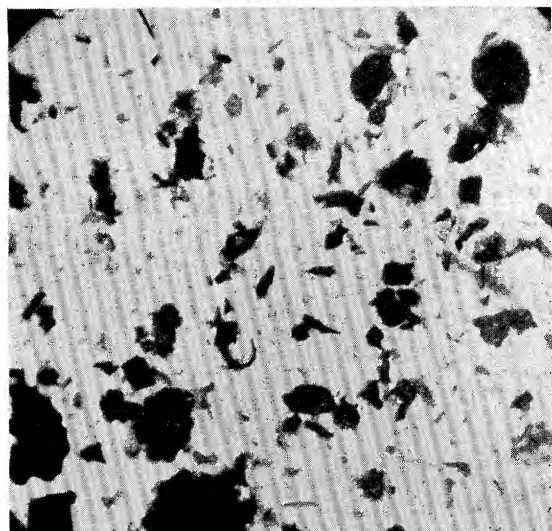
- Fig. 1.—Photograph of natural broken surface of durain. At right angles to the bedding plane. Natural size.
- Fig. 2.—Photograph of natural broken surface of clarain. At right angles to the bedding plane. Natural size.
- Fig. 3.—Photograph of natural broken surface of small block of banded clarain in the centre of which is a broad definite band of vitrain. Note: In the photograph, owing to its brilliantly refractive nature, the vitrain shows as a broad white band. At right angles to the bedding plane. Natural size.
- Fig. 4.—Broken surface of vitrain showing irregular conchoidal fractures. This was split parallel to the bedding plane. Natural size.
- Fig. 5.—Contact photo. made by placing A, durain, B, clarain, C, vitrain, on a negative and enclosing them in a darkened chamber. Notice that the image obtained thus directly from the various ingredients is much stronger from the vitrain than from the others.

Figs. 6, 7, and 8 are all of micro-photographs of the *débris* obtained by treating the three ingredients by the method described on page 477. The three photographs are all taken on the same scale of magnification and with the same time exposure.

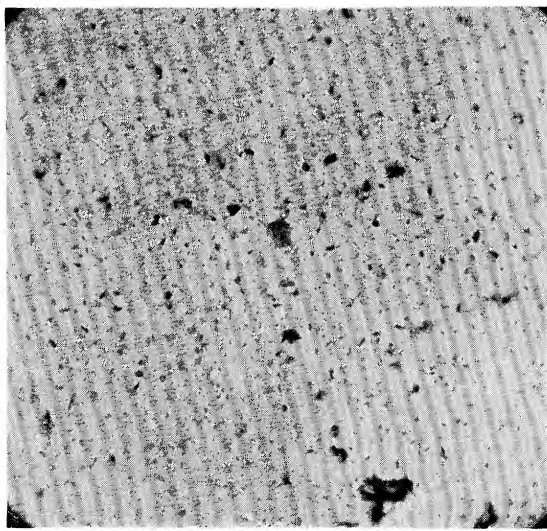
- Fig. 6.—*Débris* of fusain. Note the sharp angular shape and the solid black appearance of the fragments.
- Fig. 7.—*Débris* of durain. Note the more polyhedral shape of the black fragments and the presence of a number of less opaque ones.
- Fig. 8.—*Débris* of clarain. Note the small number of black fragments and the high proportion of clear or nearly transparent fragments. Just above the centre several spores can be seen. Note also the much smaller size of the fragments from this material than from the other two.



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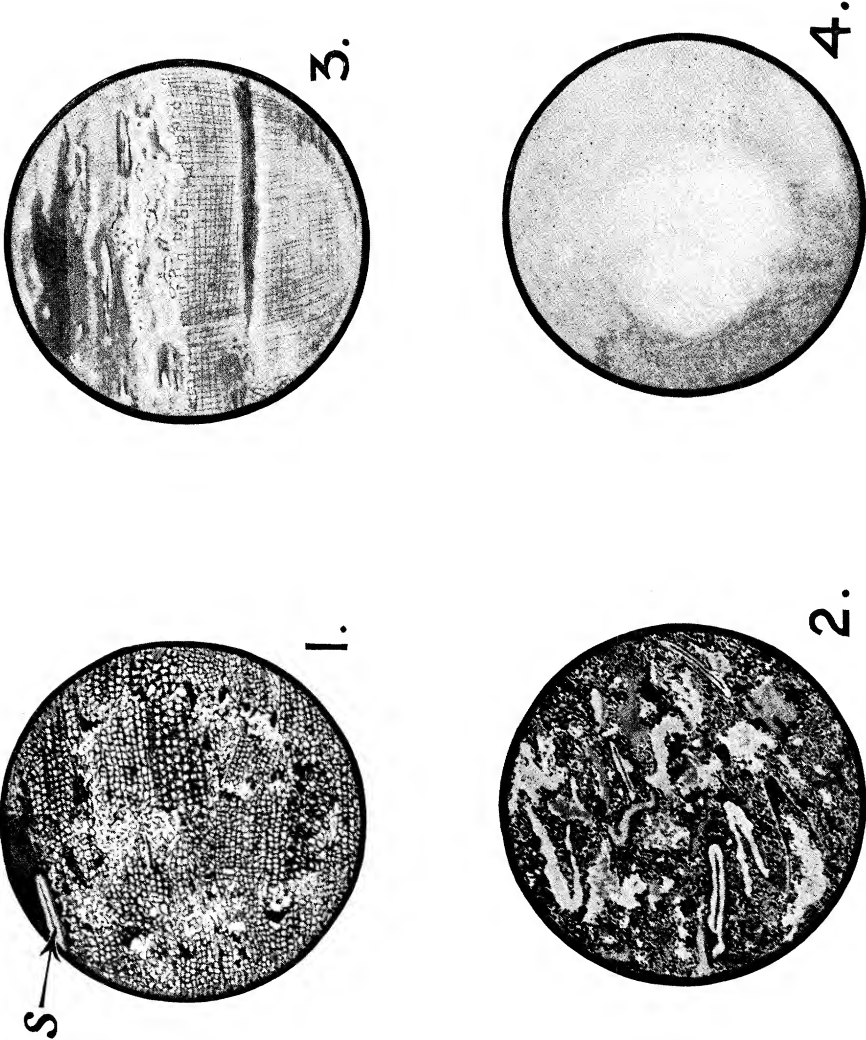
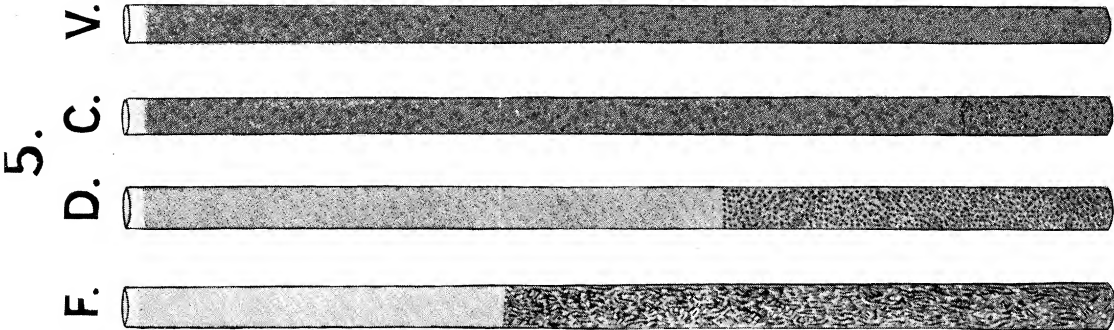


PLATE 12.—The coloured Plate.

Figs. 1-4 are all on the same scale of magnification, and represent characteristic views of the four ingredients described in this paper, as seen in micro-sections of untreated coal, showing their natural colours as seen under the microscope.

Fig. 1.—Section of fusain. At the top, note portion of a bright coloured spore from the adjacent durain. The bulk of the section is still recognisable or macerated wood fibres, the walls of which are quite black and opaque.

Fig. 2.—Section of durain. Numerous crushed and partly broken spore coats, ranging from gold to orange colour, and various small fragments are interspersed with the black granular matrix.

Fig. 3.—Section of clarain. Tissues of a stem, spores and more or less translucent bodies of various kinds, are mingled.

Fig. 4.—Section of vitrain. Showing its essential structureless condition. The various shades of colour depending upon the thickness of the section, which is never quite uniform.

Fig. 5.—Tubes showing the approximate colour and the proportion of *débris* from the four ingredients after the treatment described on page 477. F, fusain, D, durain, C, clarain, V, vitrain.

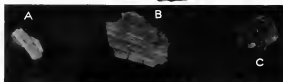
The Comparative Rate of Absorption of Various Salts by Plant Tissue.

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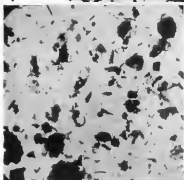
Introduction.

In a previous paper we have dealt with the intake by carrot and potato cells of single salts in different concentrations, and we there considered, especially, the dependence of the equilibrium attained in salt absorption on the concentration of the solution exterior to the tissue. In the course of these experiments dealing with the relation between concentration and intake, it was indicated that the rate of absorption and the position of equilibrium ultimately attained depended also upon the nature of the salt. As, however, experiments with different salts were made with different samples of tissue, we did not consider ourselves justified in laying much stress on the results obtained on account of the variability of different samples of tissue, a difficulty to which attention has previously been called. In the experiments recorded in this paper, we have therefore chosen one concentration and compared the conductivity changes produced in solutions of different salts by carrot and potato cells of the same sample.



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